Total vs hemi-aortic arch transposition for hybrid aortic arch repair

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Objective: **To compare the outcomes of total aortic arch transposition (TAAT) vs hemi-aortic arch transposition (HAAT) for hybrid aortic arch repair.**

Methods: **A systematic search was performed using PubMed between November 1998 and May 2010 by two independent observers. Studies included reporting on patients treated by TAAT or HAAT and stent grafting in a proximal landing zone 0 or 1 by Ishimaru, respectively. Further articles were identified by following MEDLINE links, by cross-referencing from the reference lists, and by following citations for these studies. Case reports and case series of less than five patients were excluded. Primary technical and initial clinical success, perioperative, and late morbidity and mortality were extracted per study and were meta-analyzed.**

Results: **Fourteen studies were included in the statistical analysis. The number of reported patients totaled 130 for TAAT/zone 0 and 131 for HAAT/zone 1. The primary technical success rate was significantly higher in zone 0 than 1 (95% vs 83%; odds ratio [OR], 4.0; 95% confidence interval [CI], 1.47-10.88; *P* = .0069), due to significantly higher primary type I or III endoleak rates in zone 1 (15.48% vs 3.97%; *P* = .0050). Reintervention rates were significantly higher in zone 1 (25.81% vs 12.00%; *P* = .0321). Initial clinical success rates were comparable between zone 0 and 1 (88% vs 85%; OR, 1.35; 95% CI, 0.61-3.02; *P* = .5354). In-hospital mortality was higher in zone 0 than 1 (8.46% vs 4.58%; *P* = .2212).**

Conclusion: **The more invasive TAAT allows a better landing zone at the cost of higher perioperative mortality, therefore, patient selection is crucial. (J Vasc Surg 2011;54:1182-6.)**

Open aortic arch repair necessitating deep hypothermia and circulatory arrest is offered to elderly and comorbid patients only with a considerable risk of mortality and morbidity.[1,2] Since the first report of supra-aortic vessel transposition before stent grafting of the aortic arch by Buth et al[3] in 1998, several case reports and small series have proven the feasibility and safety of arch vessel revascularization followed by endovascular repair into zone 0 and 1 (Ishimaru classification) of the aorta, as a less invasive alternative to conventional open treatment in high-risk patients.[3-20]

Yet, there are conflicting results as to the outcomes of open-endovascular hybrid aortic arch repair (HAAR) with respect to the proximal landing zone. In 2006, Bergeron et al[15] argued that total aortic arch transposition (TAAT) may be safer than the less invasive hemi-aortic arch transposition (HAAT), allowing a better landing zone. Yet, that study was limited by the relatively small sample size. The purpose of this first systematic review was to compare the outcomes of TAAT vs HAAT for HAAR in large patient cohorts and thus to enable safer conclusions.

METHODS

Literature search. A systematic search was performed using PubMed between November 1998 and May 2010. Titles and abstracts were screened by two reviewers independently to identify potentially relevant articles. Further articles were identified by following MEDLINE links, by cross-referencing from the reference lists, and by following citations for these studies.

Study eligibility. Studies were included reporting on patients treated by HAAR and with a proximal landing zone 0 or 1 according to Ishimaru.[20] In zone 0, revascularization of the brachiocephalic trunk and left common carotid artery (LCCA) with or without revascularization of the left subclavian artery was performed on the patients from the ascending aorta via median sternotomy. In zone 1, all patients received extra-anatomical revascularization of the LCCA with or without revascularization of the left subclavian artery via carotid-carotid w/carotid-subclavian bypass. In some articles, patients treated by HAAR were not the main, but a subpopulation and no detailed information was given of this subgroup. Data were included in this review if there was a separate description of these patients or if relevant data could be sufficiently retrieved from the article. At least one of the outcome parameters that are mortality, stroke, spinal cord injury, endoleaks (ELs) had to be reported. Case reports and case series of less than five patients were excluded. Studies containing duplicate material were excluded and the ones with the best-

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Competition of interest: none.

Additional material for this article may be found online at www.jvascsurg.org

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The editors and reviewers of this article have no relevant financial relationships to disclose per the JVS policy that requires reviewers to decline review of any manuscript for which they may have a competition of interest.

0741-5214/$36.00

doi:10.1016/j.jvs.2011.02.069

Table I. Indications for HAAR comparing landing zone 0 and 1

Landing zone	*No. of patients*	*Indication NR Ref VII, XI, XIII, XIV, XVII, and XVIII*	*Aneurysm*	*Dissection*	*PAU-IMH*	*Other*	*Total*
Zone 0	130	44	59	19	8	0	86
(% of reported)			69	22	9	0	100
Zone 1	131	35	51	26	17	2	96
(% of reported)			53	32	19	2	100
Total	261	79	110	45	25	2	182
(% of reported)			60	25	14	1	100

HAAR, Hybrid aortic arch repair; *NR,* number; *PAU-IMH,* penetrating aortic ulcer-intramural hematoma; *Ref,* reference.
Data are further specified in Supplemental Table I.

documented material were included for analysis. Articles were excluded if aortic arch repair was only by surgical or endovascular approaches alone or if arch transposition was performed under circulatory arrest or concomitant coronary artery revascularization.

Data extraction. The following data were extracted per study: primary technical success, initial clinical success, endoprosthesis-related complications, neurologic morbidity, mean follow-up period, reinterventions, procedure-related and total follow-up mortality, and patency of the transposition reconstructions. Two times, additional data were gathered by personal communication with the corresponding authors of the studies.[15,18] The patient demographics and risk factors were previously identified by other studies. All patients were considered to be at high surgical risk owing to serious comorbidities (American Society of Anesthesiology ≥III) or previous aortic surgery.

Definitions and statistical analysis. According to the Ishimaru/Criado classification, zone 0 extends proximal to the innominate artery and zone 1 involves the ostium of the LCCA.[19,20] ELs were categorized, as previously described by White et al.[21] ELs first observed during the perioperative (≤30 days) period were defined as primary EL. The definitions of technical and clinical success are according to the reporting standards for endovascular aortic aneurysm repair.[22] Regarding clinical success, no data on an intention-to-treat basis were available. Clinical success was claimed for those patients with a type II EL only in the absence of aneurysm expansion. Primary technical success and initial clinical success included events that occurred within the first 24 hours and 30 days after intervention, respectively.

The main endpoints, technical success and clinical success, were compared between zone 0 and 1. This study represents a "per-protocol" analysis, because there were no "no intention-to-treat" data available. As such, all patients in zone 0 were treated with TAAT, and all patients in zone 1 were treated with HAAT. SAS software (version 9.1, SAS Institute, Cary, NC) was used for statistical analysis. The differences in proportions of success rates were analyzed using the Fisher exact test. The estimates of the success rates, the corresponding odds ratios (ORs), and the differences between success rates were given with the 95% confidence intervals (CIs). Methods for estimation of success rates and ORs and methods for construction of CIs used were described in Collett.[23] If not otherwise indicated, tests used were two-sided and a statistical significance was accepted at the 5% level ($P \leq .05$).

RESULTS

The initial electronic search yielded 369 articles. After screening of titles and abstracts, and after additional searches by hand in accordance with the inclusion criteria, 14 studies were included in our statistical analysis.

Study characteristics. The number of reported patients totaled 130 for zone 0 and 131 for zone 1. The majority of patients (75% for zone 0, 67% for zone 1) were men with a mean age between 64 and 74 years old. Indications for treatment were aneurysms in more than half of the patients, followed by dissections and aortic ulcers in patients in both zone 0 and zone 1 (Table I). The urgency of the procedures is reported only by a few authors for zone 0 and zone 1 separately. An overall mean of 17% patients in zone 0 and 26% in zone 1 were treated under urgent or emergent conditions. Slightly more authors preferred a simultaneous surgical/endovascular hybrid repair over a two-stage repair. Weighted average follow-up was 21.6 months (minimum 9 months, maximum 37 months).

Technical success. The outcome parameters of the individual studies and cumulative comparative data between zone 0 and 1 with P values are presented in Table II. The primary technical success rate was significantly higher in zone 0 than in zone 1 (95% vs 83%; OR, 4.0; 95% CI, 1.47-10.88; $P = .0069$). In fact, every study but one reported higher technical success rates after TAAT than HAAT and stent grafting. In zone 0, technical success rates range between 80% and 100%. In zone 1, the rates range between 67% and 100%. The most common reason for technical failure were primary type I or III ELs, which occurred in four patients in zone 0 and 13 patients in zone 1 (3.97% vs 15.48%; $P = .0050$). In some series, type I or III EL rates were observed in up to 20% of patients in zone 0 and 33% of patients in zone 1. Type II ELs occurred in 10.00% of the patients in zone 0 vs 12.90% of the patients in zone 1. Open repair was required in a patient after TAAT and stent grafting who had a Stanford type A dissection, as well as in a patient in zone 1 developing stent collapse that could not be resolved by endovascular means.

Clinical success. Initial clinical success rates were comparable between zone 0 and 1 (88% vs 85%; OR, 1.35; 95% CI, 0.61-3.02; $P = .5354$). Three studies reported

Table IIa. Complications after HAAR comparing landing zone 0 and 1

Landing zone	*No. of patients*	*Stroke*	*Spinal cord injury*	*Type I or type III endoleak*	*Type II endoleak*
Not reported (zone 0/I)		4/11	0/0	4/47	30/69
Zone 0	130	4	1	5	10
(% of reported)		3.2	0.8	4	10
Zone 1 (% of reported)	131	5	3	13	8
(% of reported)		4.2	2.3	15.5	12.9
Total	261	9	4	18	18
(% of reported)		3.7	1.5	8.6	11.1
P value		.74	.62	.0050	.61
Odds ratio		0.75	0.33	4.43	0.75
95% confidence interval		0.20-2.88	0.03-3.22	1.52-12.95	0.28-2.02

HAAR, Hybrid aortic arch repair.
Data are further specified in Supplemental Table IIa.

Table IIb. Outcomes after HAAR comparing landing zone 0 and 1

Landing zone	*No. of patients*	*Primary technical success*	*Reinterventions*	*In-hospital mortality*	*Initial clinical success*	*Late mortality*
Not reported (zone 0/I)		4/47	30/69	0/0	4/47	40/72
Zone 0	130	120	12	11	111	0
(% of reported)		95.2	12	8.5	88.1	0
Zone 1	131	70	16	6	71	2
(% of reported)		83.3	25.8	4.6	84.5	3.4
Total	261	190	28	17	182	2
(% of reported)		90.5	17.3	6.5	86.7	1.3
P value		0.0069	0.0321	0.22	0.53	0.16
Odds ratio		4.0	2.55	1.93	1.35	N/A
95% confidence interval		1.47-10.88	1.11-5.84	0.69-5.37	0.61-3.02	N/A

HAAR, Hybrid aortic arch repair; *N/A,* not applicable.
Data are further specified in Supplemental Table IIb.

Table III. In-hospital mortality

Causes of death	*Zone 0 No. (%)*	*Zone 1 No. (%)*
Cardiac related	4 (3)	1 (1)
Stent-graft related	1 (1)	3 (2)
Stroke	2 (1.5)	0
Pulmonary	1 (1)	0
Not specified	3 (2)	2 (1.5)
Total	11 (8.5)	6 (4.5)

higher clinical success rates in zone 0, while three studies reported higher rates in zone 1. In the TAAT group, clinical success rates ranged between 79% and 100%. In the HAAT group, clinical success was achieved in between 67% and 100% of patients. In-hospital mortality was twice as high in zone 0 (11 patients) than in zone 1 (six patients; 8.46% vs 4.58%; $P = .2212$). Causes of perioperative mortality are listed in Table III. Mortality was cardiac-related in the majority of the patients in zone 0. In-hospital mortality was observed in up to 15% of the patients in zone 0 in some series, while five centers reported 0% in-hospital mortality. In the zone 1 group, mortality rates range between 0% and 25%. Reintervention rates were significantly higher after HAAT and stent grafting than TAAT (25.81% vs 12.00%; $P = .0321$). In some centers, reinterventions were necessary in up to 56% of the patients in zone 0 and 36% of the patients in zone 1.

Aortic-related mortality after hospital discharge was reported by 10 of the 14 studies and was observed in two patients in zone 1 and no patients in zone 0 (3.39% vs 0.00%; $P = .1552$). Given the short follow-up of most studies, no midterm clinical success rates could be estimated. All arterial reconstructions were patent during follow-up in both groups.

Neurologic morbidity. Strokes occurred equally in both zones. Four strokes (two major and two minor; 3.17%; $P = .7441$) occurred in zone 0 and five strokes occurred in zone 1 (two major and three minor; 4.17%). On the other hand, the paraplegia rate was higher in zone 1 compared to zone 0 (3 vs 1 event; 0.77% vs 2.29%; $P = .6221$). In fact, paraplegia was transient in zone 0, while the three patients who were paraplegic in zone 1 made no or only partial recovery.

DISCUSSION

The results of this meta-analysis indicate that the less invasive HAAT for endovascular aortic arch repair is associated with a significantly higher primary technical failure rate compared to TAAT, but that short-term clinical success rates are equally satisfactory by both methods.

HAAR has been shown to be a safe alternative to conventional open repair and may even have a lower mortality for high-risk patients, as recently suggested by Milewski et al.[24] Avoiding sternotomy, as with HAAT, seems to be the most luring alternative in often highly comorbid patients. Yet, this meta-analysis shows a significantly lower primary technical success rate of stent graft deployment into zone 1 of the aortic arch compared to TAAT and endografting in zone 0. The reasons for this include shorter landing zones (LZs) obtained by rerouting blood flow only to the LCCA. The LZ in these cases rarely exceeds 20 mm, in contrast to 30 mm of LZ that can easily be reached by TAAT. Shorter LZs along with the steeper angulation of the aortic arch in zone 1 may lead to a poorer anchoring of the stent graft and thus significantly higher type I and III EL rates in zone 1 compared to zone 0, as were seen in this study.

As a consequence of the higher type I and III EL rate in zone 1, this meta-analysis shows a significantly higher reintervention rate in zone 1 than zone 0. Thus, the observed catch-up of the zone 1 group in terms of short-term clinical success in this study is caused by higher reintervention rates in zone 1 on the one hand, and on the other hand, with the higher in-hospital mortality rate in zone 0 compared to zone 1. Certainly, TAAT is associated with significantly greater surgical trauma resulting in higher perioperative mortality in this often very comorbid patient group. This is demonstrated by the higher cardiac-related mortality in zone 0 as opposed to zone 1 patients in this study. The higher mortality rates in zone 0 were seen despite the insignificantly lower proportion of emergency procedures in this group, which are associated with increased perioperative mortality. Yet, there might be a selection bias between the groups, since TAAT is often reserved for fitter patients, as shown by our group on the basis of log Euroscore.[5] Thus, the difference in perioperative mortality might have been even bigger between the groups, were the patients at the same high risk.

Mortality was also stroke-associated in two patients in the TAAT group. Proximal extent of repair was significantly associated with a higher incidence of strokes in the past.[25] This is true when comparing stent graft anchorage into the aortic arch (zones 0-2) vs the descending thoracic aorta (zones 3-4) and is due to lengthy wire manipulation within the aortic arch. Yet, we could not identify any difference in the incidence or severity of strokes with a more proximal stent graft anchorage between zones 0 and 1.

Paraplegia rates were not significantly different between zones 0 and 1 either, but the trend observed might be informative. In fact, not only the incidence but also the severity of paraplegia was higher following HAAT vs TAAT and stent grafting. A possible explanation for this may be the insignificantly higher proportion of long segment aortic disease (eg, type B dissections) in the zone 1 group, which require long segment aortic coverage and are thus associated with an increased risk of paraplegia.[26]

The main limitation to this study is the lack of anatomic data of the two cohorts, so the results and conclusions must be cautiously interpreted in this context.

The heterogeneity of aortic pathologies in both groups, along with the different proportions of emergency procedures, the lack of use of risk stratifications systems by most authors, and, of course, the retrospective design of this study are major limitations of these results. In the future, the use of uniform reporting standards should be mandatory, in order to draw more robust conclusions from such meta-analyses.

CONCLUSIONS

Hemi-arch transposition for hybrid aortic arch repair is associated with significantly higher primary technical failure and reintervention rates compared to total-arch transposition, but with equally satisfactory initial clinical success rates. The more invasive total-arch transposition allows a better LZ at the cost of higher perioperative mortality, therefore, making patient selection crucial.

AUTHOR CONTRIBUTIONS

Conception and design: DK, PG, DB
Analysis and interpretation: DK, DB
Data collection: DK, PG, NA, AD
Writing the article: DK
Critical revision of the article: DB
Final approval of the article: DB
Statistical analysis: DK, UH
Obtained funding: Not applicable
Overall responsibility: DK, DB
DK and PG contributed equally to this article.

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Submitted Oct 25, 2010; accepted Feb 12, 2011.

Additional material for this article may be found online at www.jvascsurg.org.

INVITED COMMENTARY

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Thoracic aortic pathology involving supra-aortic branches poses a significant therapeutic dilemma for high-risk patients as endovascular therapy alone is not feasible using currently available thoracic endoprothesis. Consequently, a hybrid approach involving surgical supra-aortic vessel bypass to create an adequate landing zone followed by endovascular stent grafting has been adopted by many centers. However, the techniques for supra-aortic trunk bypass and the interventional outcomes vary significantly. In this collated review, Dr Kotelis compared the outcomes of two adjunctive surgical techniques, total aortic arch transposition for patients with zone 0 aortic diseases, and hemi-aortic arch transposition for patients with zone 1 aortic diseases. Extracting from a total of 14 case series that met inclusion criteria, Dr Kotelis and coauthors demonstrated that although both adjunctive surgical techniques for hybrid aortic arch repair had an equally satisfactory initial clinical success rate, the less invasive hemi-aortic arch transposition was associated with significantly higher primary technical failure and reintervention rates compared to the total aortic transposition. The author rightly concluded that the more invasive total-arch transposition allowed a better landing zone at the cost of higher perioperative mortality.

Dr Kotelis should be commended on the effort of taking on this difficult task by examining the existing scientific evidence. There is a paucity of well-conducted studies on this challenging clinical disease. As demonstrated by the author, the two groups of patients were extremely heterogeneous, including a mix and unmatched population of aortic aneurysm, dissection, and aortic ulcer/intramural hematoma. Additionally, two patient cohorts had different extents of aortic involvements. Patients who receive total-aortic arch repairs all had zone 0 lesions, while those who received hemi-aortic arch repair all had zone 1 lesions. Anatomic data and physiological data of the two cohorts were also not available. Therefore, the results of this collated review should be interpreted with caution. Nonetheless, Dr Kotelis' timely review on this subject helps to highlight the awareness and management difficulty of this challenging clinical dilemma. This article reveals an opportunity for a new generation of endovascular devices to treat the aortic pathology involving supra-aortic vessels.

Supplemental Table I. Indications for HAAR comparing landing zone 0 and 1

	Aneurysm		*Dissection*		*PAU-IMH*		*Other*		*Total*		
Ref	*Zone 0*	*Zone 1*	*Zone 0*	*Zone 1*	*Zone 0*	*Zone 1*	*Zone 0*	*Zone 1*	*Zone 0*	*Zone 1*	*Mean follow-up (months)*
5	8	11	0	7	2	5	0	2	10	25	33.2
6	3	8	6	9	0	0	0	0	9	17	NR
7	NR	NR	NR	NR	NR	NR	NR	NR	6	4	29.9
8	15	0	6	0	5	0	0	0	26	0	NR
9	0	19	0	5	0	12	0	0	0	36	37
10	5	8	0	0	0	0	0	0	5	8	14
11	NR	NR	NR	NR	NR	NR	NR	NR	7	2	14
12	4	0	1	0	1	0	0	0	6	0	9
13	NR	NR	NR	NR	NR	NR	NR	NR	4	11	26.2
14	NR	NR	NR	NR	NR	NR	NR	NR	14	12	28
15	9	5	6	5	0	0	0	0	15	10	15
16	15	0	0	0	0	0	0	0	15	0	18
17	NR	NR	NR	NR	NR	NR	NR	NR	8	5	16
18	NR	NR	NR	NR	NR	NR	NR	NR	5	1	8-18

HAAR, Hybrid aortic arch repair; *NR*, not reported; *PAU-IMH*, penetrating aortic ulcer-intramural hematoma; *Ref*, reference.

Supplemental Table IIa. Complications after HAAR comparing landing zone 0 and 1

	Strole		*Spinal cord injury*		*Type I or III endoleak*		*Type II endoleak*	
Ref	*Zone 0 (%)*	*Zone 1 (%)*	*Zone 0 (%)*	*Zone1 (%)*	*Zone 0 (%)*	*Zone 1 (%)*	*Zone 0 (%)*	*Zone 1 (%)*
5	0/10	2/25 (8)	0/10	1/25 (4)	2/10 (20)	6/25 (24)	3/10 (30)	2/25 (8)
6	0/9	0/17	0/9	1/17 (6)	1/9 (11)	1/17 (6)	5/9 (56)	6/17 (35)
7	1/6 (17)	0/4	1/6 (17)	0/4	0/6	0/4	1/6 (17)	0/4
8	1/26 (4)		0/26 (4)		0/26 (4)		1/26 (4)	
9		0/36		0/36	NR	NR	NR	NR
10	0/5	2/8 (25)	0/5	0/8	0/5	0/8	NR	NR
11	0/7	0/2	0/7	1/2 (50)	0/7	0/2	NR	NR
12	0/6		0/6		0/6		0/6	
13	NR	NR	0/4	0/11	NR	NR	NR	NR
14	2/14 (14)	0/12	0/14	0/12	1/14 (7)	4/12 (33)	NR	NR
15	0/15	1/10 (10)	0/15	0/10	1/15 (7)	1/10 (10)	0/15	0/10
16	0/15		0/15		0/15		0/15	
17	0/8	0/5	0/8	0/5	0/8	0/5	0/8	0/5
18	0/5	0/1	0/5	0/1	0/5	1/1 (100)	0/5	0/1

HAAR, Hybrid aortic arch repair; *NR,* not reported; *Ref,* reference.

Supplemental Table IIb. Outcomes after HAAR comparing landing zone 0 and 1

	Primary technical success		*Initial clinical success*		*In-hospital mortality*		*Reintervention*		*Late mortality*	
Ref	*Zone 0 (%)*	*Zone 1 (%)*	*Zone 0 (%)*	*Zone 0 (%)*	*Zone 0 (%)*	*Zone 1 (%)*	*Zone 0 (%)*	*Zone 1 (%)*	*Zone 0 (%)*	*Zone 1 (%)*
5	8/10 (80)	19/25 (76)	8/10 (80)	19/25 (76)	1/10 (10)	1/25 (4)	5/10 (50)	9/25 (36)	NR	NR
6	8/9 (89)	16/17 (94)	8/9 (89)	5/17 (94)	1/17 (11)	0/17	5/9 (56)	6/17 (35)	0/9	0/17
7	6/6 (100)	4/4 (100)	5/6 (83)	4/4 (100)	0/6	1/4 (25)	1/6 (17)	0/4	0/6	0/4
8	26/26 (100)		22/26 (85)		4/26 (15)		0/26		NR	
9		NR		NR		2/36 (5.5)		NR		NR
10	5/5 (100)	8/8 (100)	5/5 (100)	8/8 (100)	0/5	0/8	NR	NR	0/5	0/8
11	7/7 (100)	2/2 (100)	7/7 (100)	2/2 (100)	0/7	0/2	NR	NR	0/7	0/2
12	6/6 (100)		6/6 (100)		0/6		0/6		0/6	
13	NR	NR	NR	NR	0/4	1/11 (9)	NR	NR	NR	NR
14	13/14 (93)	8/12 (66)	11/14 (79)	8/12 (66)	2/14 (14)	0/12	NR	NR	0/14	2/12 (17)
15	13/15 (87)	8/10 (80)	13/15 (87)	8/10 (80)	1/15 (7)	1/10 (10)	0/15	0/10	0/15	0/10
16	15/15 (100)		14/15 (93)		1/15 (7)		1/15 (7)		0/15	
17	8/8 (100)	5/5 (100)	7/8 (87.5)	5/5 (100)	1/8 (12.5)	0/5	0/8	0/5	0/8	0/5
18	5/5 (100)	0/1	5/5 (100)	1/1 (100)	0/5	0/1	0/5	1/1 (100)	0/5	0/1

HAAR, Hybrid aortic arch repair; *NR,* not reported; *Ref,* reference.